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PECULIARITIES OF INTERACTION OF Cu-W COMPOSITE MATERIALS WITH THERMAL ARC DISCHARGE PLASMA

A. Murmantsev[1], A. Veklich[1], V. Boretskij[1], M. Kleshych[1], S. Fesenko[1], M. Bartlova[2]

[1]Taras Shevchenko National University of Kyiv, Kyiv, Ukraine;
[2]Brno University of Technology, Brno, Czech Republic

E-mail: murmantsev.aleksandr@gmail.com

This work is a part of acomplex investigation of the interaction of Cu-W composite materials with thermal electric arc discharge plasma. The plasma of 3.5 A DC arc discharge between novel Cu-W composite materials, fabricated by shock pressing technology at the temperature of 750°C, was studied at this stage. Spectra of such plasma emission were registered and treated to determine the radial distributions of plasma temperature in three different cross-sections of the plasma channel, namely in near-cathode, near-anode and middle cross-sections.

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INTRODUCTION

Nowadays, there is still interest growing in studying the thermal effect of the plasma of electric discharges, which occur during the operation of switching devices, on their electrodes/contacts surface. The implementation of innovative developments continues and the main research approaches in this field are permanently improved and optimized. The reason for this development is the need to meet the necessities of the power industry.

So, for example, due to the need to increase the productivity of arc welding, compositions of two arcs are being developed [1] (tandem arc welding), a combination of a laser beam with an arc [2] (hybrid laser-arc welding), the use of plasmatrons [3] (plasma welding) and the application of pulse power sources [4] (pulse arc welding). Such new trends, even with small improvements in efficiency and productivity, can make a significant contribution to industries such as shipbuilding and aircraft construction, which require a large volume of high-quality welds.

Moreover, new variants of already known processes of plasma sputtering of solutions and suspensions are being developed [5], the efficiency of creating thin films by the magnetron method is improved [6], variations are increased and the characteristics of synthesized solutions with nanoparticles are improved [7], etc.

In addition to the direct practical application of thermal plasma, there is a study of its negative effect on the materials of contacts and electrodes of switching devices. It is well-known, during the switching of electrical circuits (for example, in electric and gas switches for high and medium voltage equipment, in collector motors, generators, electric trains, in switches of distribution systems of medium and high degree of load, etc.), an electric arc occurs, which causes significant erosion of contact materials. Such a process naturally leads to a reduction in the service life, a decrease in work efficiency, and a number of other negative consequences in such devices.

Obviously, to prevent or solve such problems in switching devices, there is a need to create novel and improve existing electrodes and contact materials. One such material is a composite based on copper and tungsten.

Composite Cu-W electrodes are in great demand due to the wide possibilities of their practical application, such as welding electrodes, electrical contacts, materials for heat dissipation in integrated circuits with a high degree of integration, arc tips and microwave materials, high-temperature erosion materials, ballasts of various shapes and sizes, jet blades, X-ray screens, divertor plates for thermonuclear reactors [8, 9], etc.

The main aim of this work, as a part of the complex investigation, is to carry out the preliminary diagnostics of thermal plasma of electric arc discharge between composite Cu-W electrodes by optical emission spectroscopy techniques and determination of the possibility of their use for investigation of the interaction of thermal plasma of arc discharge with novel Cu-W composite materials.

1. EXPERIMENT

The DC electric arc discharges of 3.5 A were initiated between vertically-oriented square in section (5×5 mm) electrodes made from Cu-W50 vol.% composite material fabricated by shock pressing technology at the temperature of 750 °C. The three different cross-sections of the plasma channel, namely cross-sections near to anode and cathode and in the middle cross-section between electrodes, were investigated.

The registration device with spatial and spectral resolution [10] was used to obtain the emission spectra of plasma with Cu and W vapours admixtures from different cross-sections of the arc channel. The images shown in Fig. 1 were obtained by RGB CCD camera with the exposure time of 1/400 s (a, c), 1/1000 s (b). Neutral filter NG8 was used (a, c) [11]in order to extend the dynamic range.

The spectra emission intensity converted into grayscale with taking into account spectral sensitivity and absorption coefficients of filter are shown in Fig. 2. Ten points in radial directions from the axis of the plasma channel were selected and spectral profiles of both Cu I and W I spectral lines were selected and approximated by the Voigt function in each of these points. Typical approximations of spectral lines profiles are shown in Fig. 3. Thus, the spatial (radial) profiles of each spectral lines were obtained (see Fig. 4).

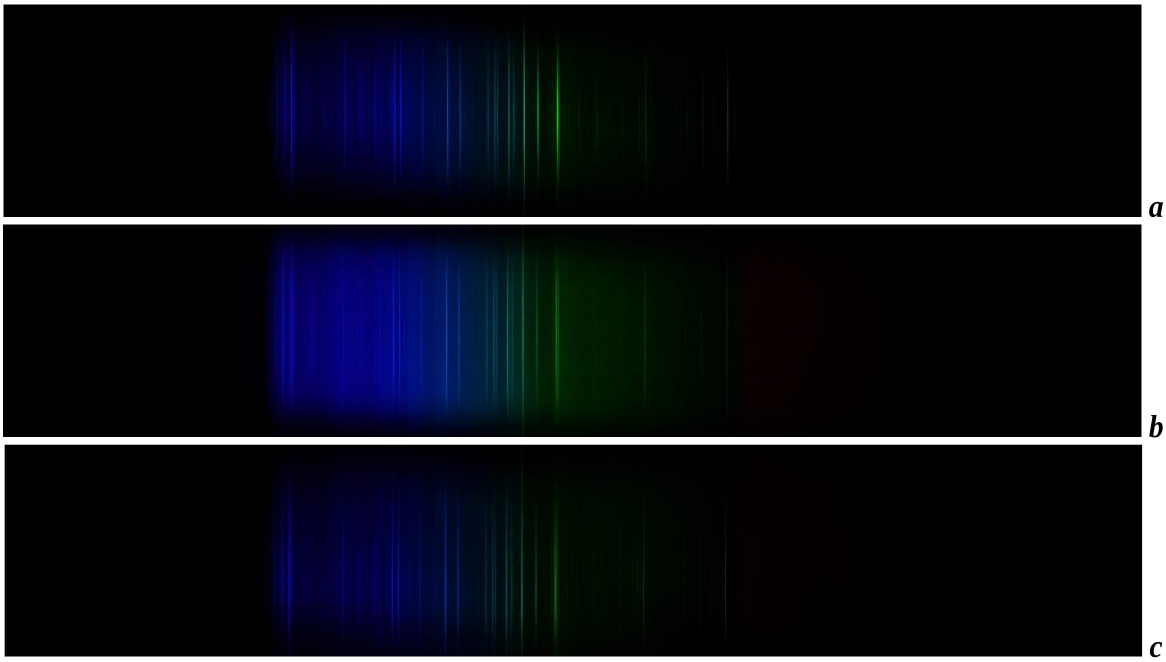

Fig. 1. Emission spectra with spatial and spectral resolution registered from near-anode (a), middle (b) and near-cathode (c) cross-sections of arc discharge channel

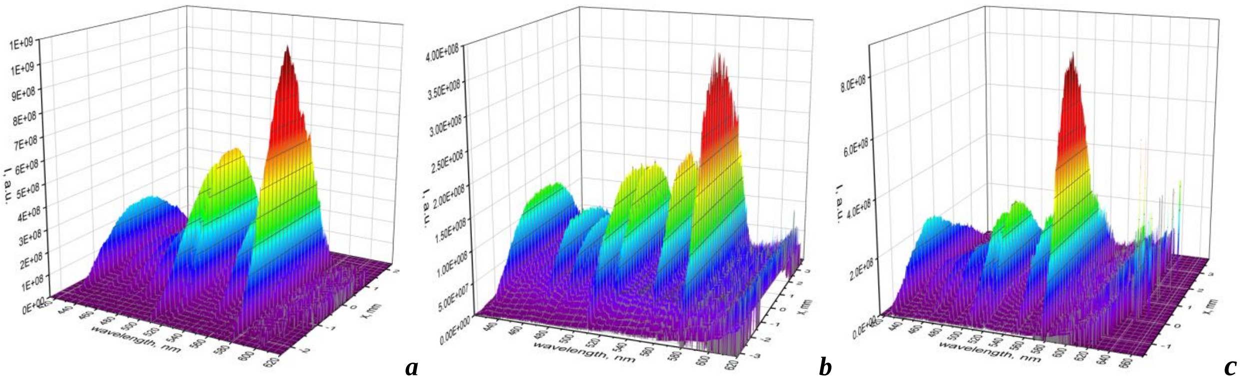

Fig. 2. Emission spectra with spatial and spectral resolution with taking into account spectral sensitivity registered from near-anode (a), middle (b) and near-cathode (c) cross-sections of arc discharge channel

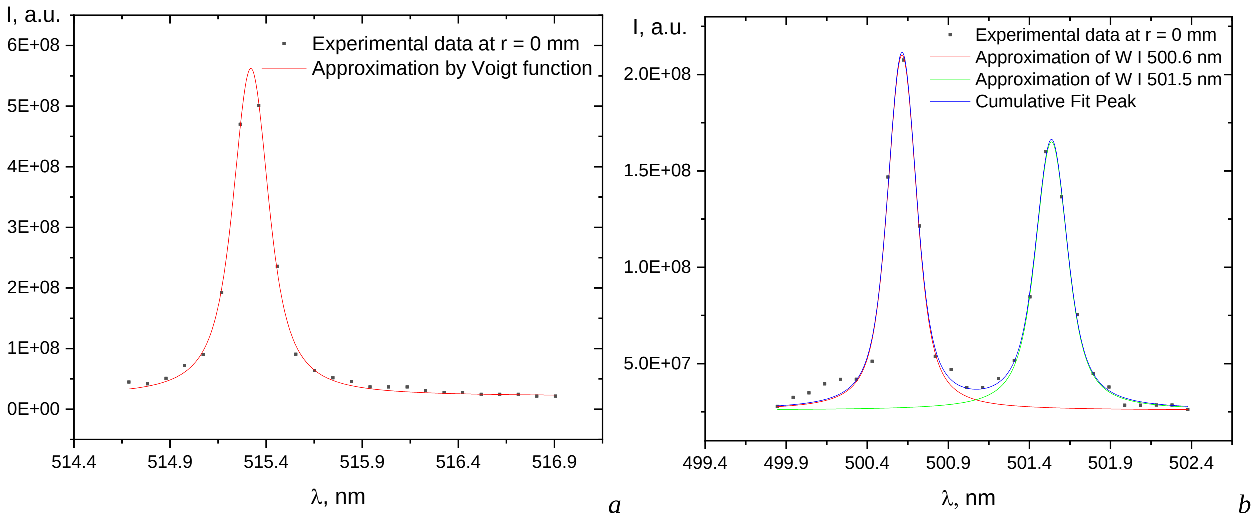

Fig. 3. Typical approximations of spectral profiles of Cu I 515.3 nm (a) and W I 500.6, 501.5 nm (b) lines by Voigt function

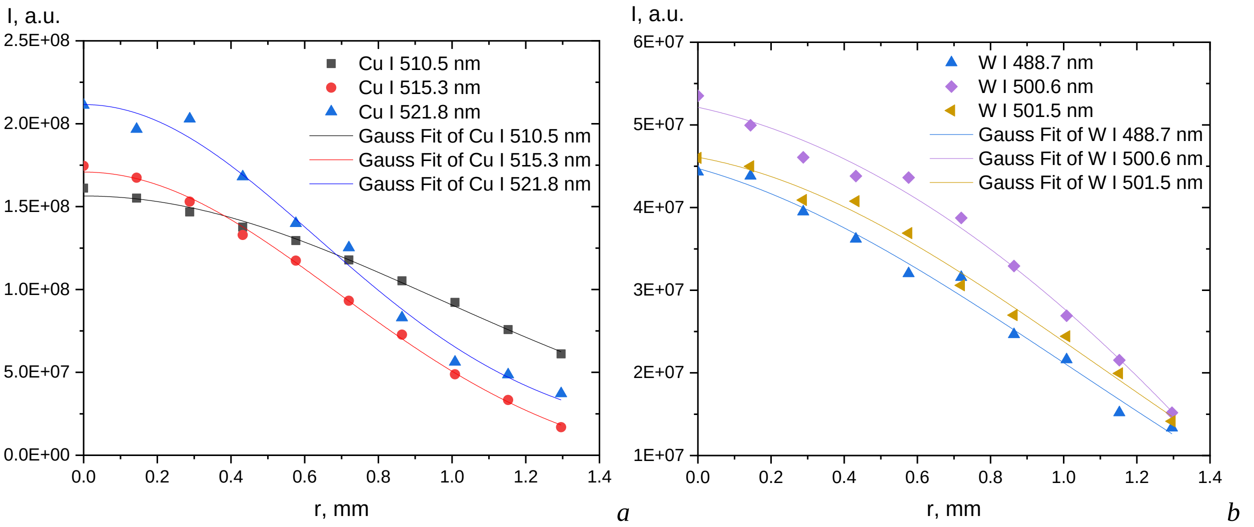

Fig. 4. Typical approximations of spatial profiles of Cu I (a) and W I (b) lines by Gauss function (emission intensity obtained from near-anode cross-section)

The Gauss function was used to approximate the spatial profiles to obtain the differentiable function in order to transform the observed emission intensity into its local values by the Bockasten method [12].

These local values of emission intensity of selected spectral lines were used to determine plasma temperature by the Boltzmann plot technique [13].

2. RESULTS AND DISCUSSIONS

As mentioned above, both copper and tungsten atomic spectral lines were used in this work. Namely, the spectral profiles of Cu I 510.5, 515.3, 521.8 nm and W I 468.1, 488.7, 498.3, 500.6, 501.5, and 522.5 nm spectral lines were selected from spectra, approximated and used in the determination of plasma temperature. Typical Boltzmann plots on the basis of the aforementioned spectral lines are shown in Fig. 5. The spectroscopic data for each of these lines were preliminarily selected in previous works [14, 15].

One can see, that approximating straight lines coincide almost exactly with the calculated points on the Boltzmann plot based on Cu I spectral lines, which indicates that temperature is determined with high accuracy (< 10 %).

The accuracy of temperature determination by plots on the basis of W I spectral lines has a more significant error (< 20 %). Such error is due to the narrow range of energy of upper levels of the selected tungsten spectral lines (0.82 eV compared with 2.38 eV of copper). It is obvious, that the narrower the energy range, the greater the error in determining the temperature for the same errors in determining the value $ln(I\lambda^3/gf)$.

The radial distributions of plasma temperature determined by the Boltzmann plot technique based on both Cu I and W I obtained from near-anode, middle and near-cathode cross-sections of the arc discharge channel are shown in Fig. 6.

One can see, that temperatures obtained in different cross-sections differ along the discharge gap, especially at the axial points (r = 0 mm) of the discharge channel. This can be explained by a significant difference in metal components concentrations at different points of the arc. Naturally, the lower temperature can indicate the higher content of metal evaporated from electrode's surface. Thus, it can be assumed, the material of the composite electrode evaporates more strongly in the near-cathode region compared to the near-anode one.

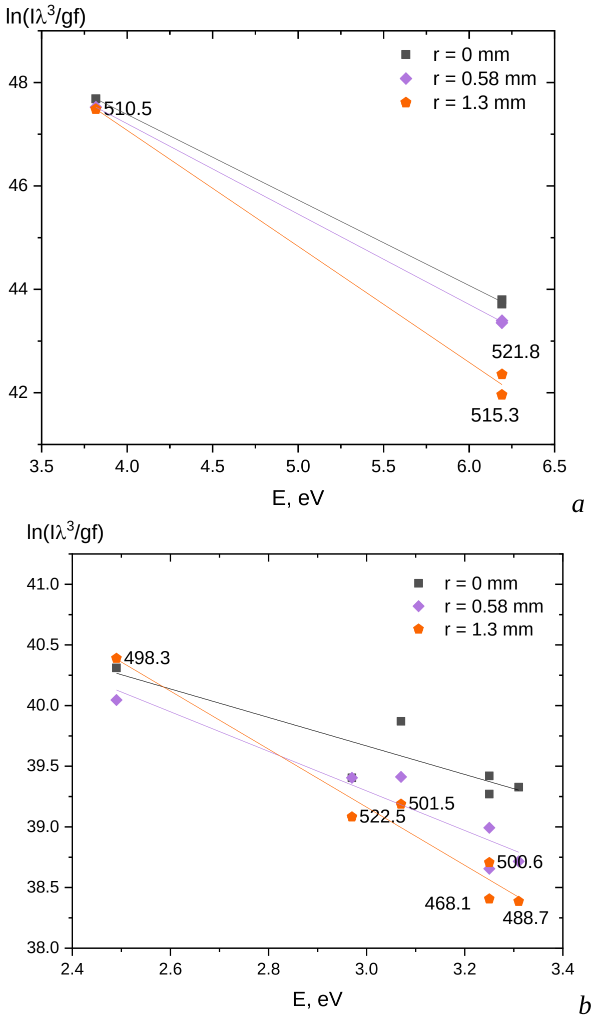

Fig. 5. Typical Boltzmann plots based on emission intensity of Cu I 510.5, 515.3, 521.8 nm (a) and W I 468.1, 488.7, 498.3, 500.6, 501.5 and 522.5 nm (b) spectral lines (emission intensity obtained from near-anode cross-section)

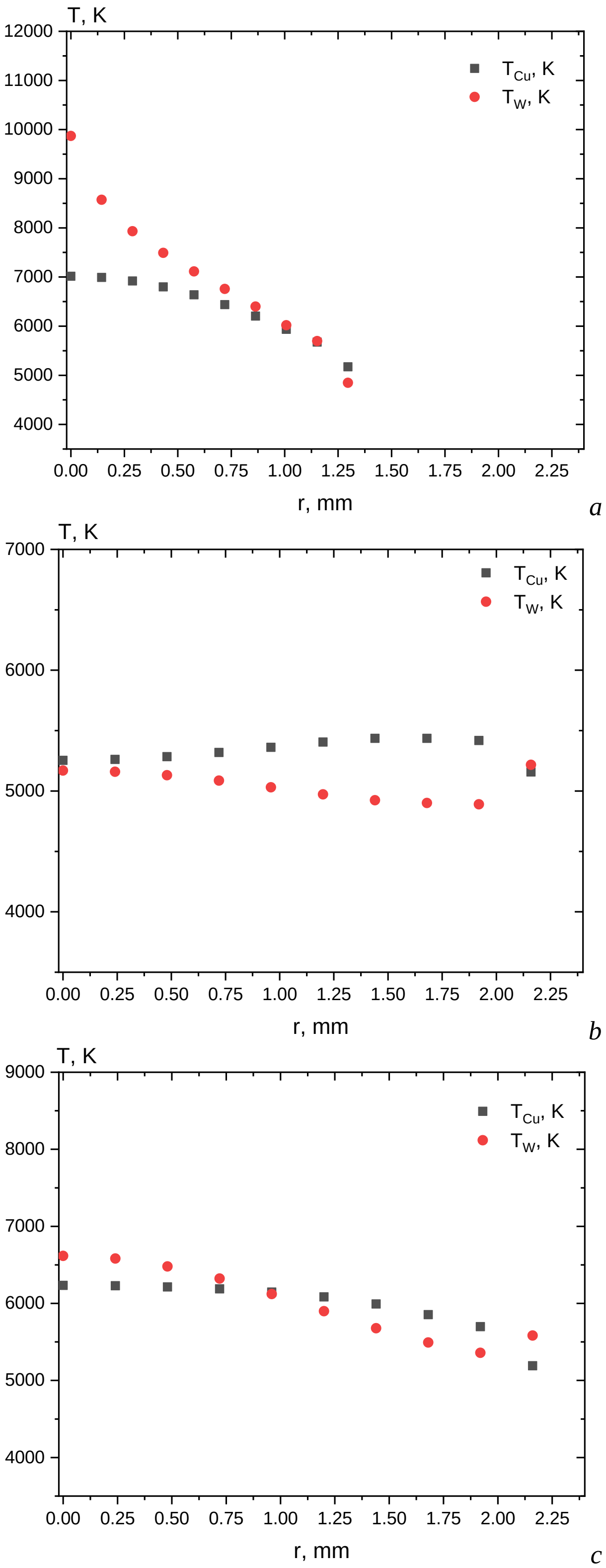

Fig. 6. Radial distributions of plasma temperature, obtained by Boltzmann plot technique based on Cu I and W I spectral lines registered from near-anode (a), middle (b) and near-cathode (c) cross-sections of arc discharge channel

Moreover, the radial distribution of temperatures obtained on the basis of emission intensity of both atomic copper and tungsten spectral lines coincides within the range of measurements error at most radial points of discharge channel. This allows us to draw the conclusion that the local thermodynamic equilibrium is realized in all three investigated cross-sections of the discharge gap between the copper-tungsten composite electrodes.

CONCLUSIONS

The novel Cu-W composite material fabricated by shock pressing technology at the temperature of 750 °C was studied in interaction with 3.5 A DC current arc discharge plasma. Spectra of such plasma emission were registered and treated to determine the radial distributions of plasma temperature in three different cross-sections of the plasma channel, namely in near-cathode, near-anode and middle cross-sections.

It was found, that the radial distribution of temperatures obtained on the basis of emission intensity of both atomic copper and tungsten spectral lines coincides within the range of measurements error at most radial points of the discharge channel. This indicates that local thermodynamic equilibrium can realize in all three investigated cross-sections of the discharge gap between the copper-tungsten composite electrodes.

The results obtained in this work allow us to carry out further investigations of the thermal plasma of electric arc discharge between other types of novel Cu-W composite electrodes, namely fabricated at variable manufacturing parameters. Moreover, the erosion resistance of all of these types of composite electrodes should be estimated by determination of the content of metal vapours in discharge gap.

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ОСОБЛИВОСТІ ВЗАЄМОДІЇ КОМПОЗИТНИХ МАТЕРІАЛІВ Cu-W З ТЕРМІЧНОЮ ПЛАЗМОЮ ДУГОВОГО РОЗРЯДУ

О. Мурманцев, А. Веклич, В. Борецький, М. Клешич, С. Фесенко, М. Бартлова

Описано частину комплексного дослідження взаємодії Cu-W композитних матеріалів з термічною плазмою електродугового розряду. На цьому етапі роботи досліджувалась плазма дугового розряду постійного струму 3,5 А між новітніми композитними матеріалами Cu-W, які виготовлені за технологією ударного пресування при температурі 750°C. Зареєстровано та оброблено спектри випромінювання такої плазми з метою визначення радіального розподілу температури в трьох різних поперечних перерізах плазмового каналу, а саме в прикатодному, прианодному та середньому перерізах.